

PATENT OFFICE  
JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy of the following application as filed with this Office.

Date of Application: February 27, 2003

Application Number: Japanese Patent Application  
No. 051762/2003

Applicant(s): TDK Corporation

Commissioner,

Patent Office

(Seal)

(Document Name) Patent Application  
(Reference Number) 99P04772  
(Presentation Date) February 27, 2003  
5 (Directly) Commissioner of the Patent  
Office  
(IPC) H01L 41/083  
(Inventor)  
(Residence or Address)  
10 c/o TDK Corporation, 1-13-1, Nihonbashi, Chuo-ku,  
Tokyo, Japan  
(Name) Satoshi SASAKI  
(Inventor)  
(Residence or Address)  
15 c/o TDK Corporation, 1-13-1, Nihonbashi, Chuo-ku,  
Tokyo, Japan  
(Name) Kazushi TACHIMOTO  
(Applicant)  
(Identification Number) 000003067  
20 (Name) TDK Corporation  
(Attorney)  
(Identification Number) 100088155  
(Patent Attorney)  
(Name) Yoshiki HASEGAWA  
25 (Attorney)  
(Identification Number) 100092657

(Patent Attorney)

(Name) Shiro TERASAKI

(Attorney)

(Identification Number) 100108213

5 (Patent Attorney)

(Name) Toyotaka ABE

(Official Fee)

(Pre-Paid Master Note Number) 014708

(Amount to be paid) 21,000 yen

10 (Lists of the Article to be presented)

|                   |               |   |
|-------------------|---------------|---|
| (Name of Article) | Specification | 1 |
|-------------------|---------------|---|

|                   |         |   |
|-------------------|---------|---|
| (Name of Article) | Drawing | 1 |
|-------------------|---------|---|

|                   |          |   |
|-------------------|----------|---|
| (Name of Article) | Abstract | 1 |
|-------------------|----------|---|

(Proof Reading) Require

[Document Name] Specification

[Title of the Invention] Multilayer Piezoelectric  
Element

5 [Claims]

[Claim 1] A multilayer piezoelectric element in  
which a piezoelectric layer is disposed between a first  
internal electrode and a second internal electrode,

10 wherein the first internal electrode has an  
electrode portion for producing, in cooperation with  
the second internal electrode, an electric field in  
the piezoelectric layer, and a connection portion  
connected to a conductive substance in a through hole  
formed in the piezoelectric layer; and

15 wherein the connection portion is formed at a  
position shifted from the longitudinal centerline of  
the electrode portion.

[Claim 2] A multilayer piezoelectric element  
according to claim 1, wherein the first internal  
20 electrode is an individual electrode, and a plurality  
of individual electrodes are formed on one face of  
the piezoelectric layer.

[Claim 3] A multilayer piezoelectric element  
according to claim 2, wherein the plurality of  
25 individual electrodes are disposed in a matrix on the  
piezoelectric layer.

[Claim 4] A multilayer piezoelectric element according to claim 2 or 3, wherein the connection portion is positioned between adjacent electrode portions.

[Claim 5] A multilayer piezoelectric element according to one of claims 2 to 4, wherein the second internal electrode is a common electrode, and is formed on the other face of the piezoelectric layer while having a shape to overlay the electrode portion across the piezoelectric layer.

[Claim 6] A multilayer piezoelectric element according to one of claims 1 to 5, further comprising an outermost layer laminated on a top of a plurality of piezoelectric layers;

wherein the outermost layer has an external electrode opposed to the connection portion in a thickness direction of the piezoelectric element.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention Pertains]

The present invention relates to a multilayer piezoelectric element used as a driving source for minute displacements, such as valve control of micropumps.

[0002]

[Prior Art]

This kind of conventional multilayer piezoelectric element is disclosed in the following Patent Document 1, for example. In this multilayer piezoelectric element, piezoelectric layers each patterned with a number of individual electrodes and piezoelectric layers each patterned with a common electrode are alternately laminated, whereas the individual electrodes aligning in the thickness direction of the multilayer piezoelectric element are connected to each other by conductive substances by way of through holes formed in the piezoelectric layers. When a voltage is applied between a predetermined individual electrode and a common electrode, such a multilayer piezoelectric element can selectively displace an active portion (where a distortion is generated by a piezoelectric effect) corresponding to the predetermined individual electrode in the piezoelectric layers.

[0003]

[Patent Document 1]

Japanese Patent Application Laid-Open No.  
2002-254634

[0004]

[Problem to be Solved by the Invention]

However, since respective ends of the individual electrodes aligning in the thickness direction are

connected to each other by conductive substances, the  
above-mentioned conventional multilayer  
piezoelectric element may be problematic in that  
active portions are restrained from being displaced  
5 between the individual electrodes, thus lowering their  
amount of displacement. Such a problem becomes more  
remarkable as the individual electrodes are made  
smaller in order to reduce the size of the multilayer  
piezoelectric element or attain a higher integration  
10 of individual electrodes.

[0005]

In view of such circumstances, it is an object  
of the present invention to provide a multilayer  
piezoelectric element which can prevent the amount  
15 of displacement of active portions in piezoelectric  
layers from decreasing.

[0006]

[Means for Solving the Problem]

For achieving the above-mentioned object, the  
20 present invention provides a multilayer piezoelectric  
element in which a piezoelectric layer is disposed  
between a first internal electrode and a second  
internal electrode, wherein the first internal  
electrode has an electrode portion for producing, in  
25 cooperation with the second internal electrode, an  
electric field in the piezoelectric layer, and a

connection portion connected to a conductive substance  
in a through hole formed in the piezoelectric layer;  
and wherein the connection portion is formed at a  
position shifted from the longitudinal centerline of  
the electrode portion.

[0007]

In the piezoelectric layer of this multilayer  
piezoelectric element, a portion held between the  
electrode portion of the first and second internal  
electrodes becomes an active portion, which is  
displaced when a voltage is applied between the first  
and second inner electrodes. The first inner  
electrode includes a connection portion connected to  
the conductive substance in the through hole of the  
piezoelectric layer, which is formed at a position  
shifted from the longitudinal centerline of the  
electrode portion. This can restrain the  
displacement of the electrode portion following the  
active portion of the piezoelectric layer from being  
suppressed by the connection with the conductive  
substance. Therefore, this multilayer piezoelectric  
element can prevent the amount of displacement of the  
active portion in the piezoelectric layer from  
decreasing. Here, "the longitudinal centerline of  
the electrode portion" refers to a line passing  
substantially the center of the width (in the direction

orthogonal to the longitudinal direction) of the electrode portion along the longitudinal direction thereof.

[0008]

5            Preferably, the first internal electrode is an individual electrode, and a plurality of individual electrodes are formed on one face of the piezoelectric layer. This is because, as mentioned above, the suppression of the displacement of the electrode  
10           portion following the active portion of the piezoelectric layer is alleviated in the first internal electrode, whereby a plurality of internal electrodes formed as individual electrodes can be made smaller.

15           [0009]

            Preferably, the plurality of individual electrodes are disposed in a matrix on the piezoelectric layer. This makes it possible for the plurality of individual electrodes to be disposed  
20           efficiently on the piezoelectric layer.

[0010]

            Preferably, the connection portion is positioned between adjacent electrode portions. When the first internal electrode is an individual electrode, and  
25           a plurality of individual electrodes are formed, it is necessary to provide a predetermined gap between

adjacent electrode portions in order to electrically separate them from each other. Positioning the connection portion in the gap allows the individual electrodes to be disposed more efficiently in the piezoelectric layer. This allows the multilayer piezoelectric element to be made smaller or the individual electrodes to attain a higher integration, while keeping the area of each active portion.

[0011]

Preferably, the second internal electrode is a common electrode, and is formed on the other face of the piezoelectric layer while having a shape to overlay the electrode portion across the piezoelectric layer. Forming the second internal electrode as a common electrode as such facilitates the forming of the second internal electrode and the positioning with respect to its opposing first internal electrode. Since the second internal electrode has a shape to overlay the electrode portion across the piezoelectric layer, the portion of the piezoelectric layer opposing each electrode portion as a whole can efficiently be used as an active portion.

[0012]

Preferably, the multilayer piezoelectric element comprises an outermost layer laminated on a top of a plurality of piezoelectric layers, and the

outermost layer has an external electrode opposed to the connection portion in a thickness direction of the piezoelectric element. While a lead to connect with a driving power supply, for example, is attached to the external electrode formed with the outermost layer, the external electrode is formed at a position opposed to the connection portion of the first internal electrode (i.e., the corresponding position in the thickness direction of the piezoelectric element). This can prevent the lead from pressing the electrode portion of the first internal electrode and the active portion of the piezoelectric layer and inhibiting their displacement.

[0013]

[Embodiments of the Invention]

In the following, preferred embodiments of the present invention will be explained in detail with reference to the accompanying drawings. Constituents identical to each other will be referred to with numerals identical to each other without repeating their overlapping explanations.

[0014]

[First Embodiment]

As shown in Fig. 1, the multilayer piezoelectric element 1 in accordance with the first embodiment is constructed such that four piezoelectric layers 3 each

formed with individual electrodes (first internal electrodes) 2 and four piezoelectric layers 5 each formed with a common electrode (second internal electrode) 4 are alternately laminated, and thus  
5 formed laminate is held between a piezoelectric layer (outermost layer) 7 to be formed with terminal electrodes and a base piezoelectric layer 9 from the upper and lower sides, respectively. In other words, the piezoelectric layers 3, 5 are held between the  
10 individual electrodes 2 and common electrodes 4.

[0015]

Each of the piezoelectric layers 3, 5, 7, 9 is mainly composed of ceramics such as lead zirconate titanate and is formed into a thin rectangular sheet  
15 of 10 mm × 30 mm with a thickness of 30 μm, for example. The individual electrodes 2 and common electrodes 4 are mainly composed of silver and palladium, for example, and formed as patterns by screen printing. The same applies to electrodes which will be explained  
20 in the following.

[0016]

In the multilayer piezoelectric element 1, a number of individual electrodes 2 are disposed in a matrix on the upper face of each of the third, fifth, and seventh piezoelectric layers 3a from the uppermost  
25 (outermost) piezoelectric layer 7 as shown in Fig.

2. Assuming that rows align in the longitudinal direction of the piezoelectric layer 3a, and that columns align in a direction perpendicular to the longitudinal direction, the individual electrodes are arranged in a matrix of 4 columns by 75 rows (only 4 columns by 20 rows being depicted for the sake of clarification), for example. Disposing a number of individual electrodes 2 into a matrix as such enables an efficient arrangement with respect to the piezoelectric layer 3a. Adjacent individual electrodes 2, 2 have a predetermined gap therebetween, so as to be electrically separated from each other, and kept from affecting each other upon vibration.

[0017]

An end part of the upper face of each piezoelectric layer 3a is formed with an intermediate electrode 6 for electrically connecting respective common electrodes 4, 4 of the piezoelectric layers 5 positioned on the upper and lower sides. The intermediate electrode 6 is connected directly thereunder to a conductive substance in a through hole 8 formed in the piezoelectric layer 3a.

[0018]

As shown in Fig. 3, the individual electrode 2 includes a rectangular electrode portion 11 for producing, in cooperation with the common electrode

4, an electric field in the piezoelectric layer 3a. The electrode portion 11 is arranged such that its longitudinal direction is orthogonal to the longitudinal direction of the piezoelectric layer 3a.

5 A square connection portion 12 joins with one end part 11a of the electrode portion 11 in the longitudinal direction. The electrode portion 11 and connection portion 12 are integrally formed by way of a narrow neck portion 12a such that the center (i.e., center  
10 of gravity) position of the connection portion 12 is displaced from the longitudinal centerline L of the electrode portion 11 (i.e., line passing the center of gravity of the electrode portion 11).

[0019]

15 Thus shaped individual electrodes 2 are disposed such that the connection portions 12 are positioned adjacent each other in the first and second columns and in the third and fourth columns. Each connection portion 12 is connected directly thereunder to the  
20 conductive substance in the through hole 13 formed in the piezoelectric layer 3a.

[0020]

Individual electrodes 2 are also disposed in a matrix on the upper face of the ninth piezoelectric layer 3b as in the third, fifth, and seventh  
25 piezoelectric layers 3a. However, as shown in Fig.

4, the ninth piezoelectric layer 3b differs from the piezoelectric layers 3a in that no through holes 13 are formed.

[0021]

5 As shown in Fig. 5, intermediate electrodes 16 are formed on the upper face of each of the second, fourth, sixth, and eighth piezoelectric layers 5 from the uppermost piezoelectric layer 7 so as to oppose their corresponding connection portions 12 of the  
10 piezoelectric layers 3 in the thickness direction of the multilayer piezoelectric element 1. (In the following, "the thickness direction of the multilayer piezoelectric element 1", i.e., "the thickness direction of the piezoelectric layers 3, 5", will  
15 simply be referred to as the thickness direction.) Each intermediate electrode 16 is connected directly thereunder to the conductive substance in the through hole 13 formed in the piezoelectric layer 5.

[0022]

20 The common electrode 4 is formed on the upper face of the piezoelectric layer 5. The common electrode 4 surrounds each of an assembly of the intermediate electrodes 16 in the first and second columns and an assembly of the intermediate electrodes 16 in the third  
25 and fourth columns with a predetermined gap therebetween. As shown in Fig. 3, the common electrode

4 has a shape to overlay the electrode portions 11 across the piezoelectric layers 3, 5 (on the upper face thereof). In other words, the common electrode 4 has a shape to overlay the electrode portions 11 of the piezoelectric layer 3 as a whole as seen in the thickness direction. As a consequence, the whole part opposing the electrode portions 11 in the piezoelectric layers 3, 5 can effectively be used as an active portion contributing to vibration.

[0023]

The common electrode 4 is formed with a predetermined gap from the outer peripheral part of the piezoelectric layer 5. The common electrode 4 is connected to the conductive substance in the through hole 8. The through hole 8 is formed in the piezoelectric layer 5 so as to oppose the intermediate electrode 6 in the piezoelectric layer 3 in the thickness direction.

[0024]

As shown in Fig. 6, the upper face of the uppermost piezoelectric layer 7 is formed with external electrodes 17 opposed to their corresponding intermediate electrodes 16 of the piezoelectric layer 5 in the thickness direction, and an external electrode 18 opposed to the intermediate electrode 6 of the piezoelectric layer 3 in the thickness direction.

Each external electrode 17 is connected directly thereunder to the conductive substance in the through hole 13 formed in the piezoelectric layer 7, whereas the external electrode 18 is connected directly thereunder to the conductive substance in the through hole 8 formed in the piezoelectric layer 7. Each of the external electrodes 17, 18 is provided with a silver baked electrode for attaching thereto a lead to be electrically connected to a driving power supply, and functions as a terminal electrode for the multilayer piezoelectric element 1.

[0025]

As shown in Fig. 7, on the upper face of the lowermost piezoelectric layer 9, a rectangular common electrode 19 having an outer form equivalent to that of the common electrode 4 of the piezoelectric layer 5 is formed with a predetermined gap from the outer peripheral part of the piezoelectric layer 9.

[0026]

The piezoelectric layers 3, 5, 7, 9 thus formed with the electrode patterns are laminated, whereby each piezoelectric layer 3 is formed with the individual electrodes 2 on the upper face as one face, and the common electrode 4 or 19 on the lower face as the other face. On the other hand, each piezoelectric layer 5 is formed with the individual

electrodes 2 on the lower face as one face, and the common electrode 4 or 19 on the upper face as the other face.

[0027]

5 Four individual electrodes 2 align with each of the external electrodes 17 in the uppermost external electrodes 17 in the thickness direction while the intermediate electrodes 16 are interposed therebetween, so that thus aligned electrodes 2, 16,  
10 17 are electrically connected to each other by the conductive substance within their corresponding through hole 13. More specifically, as shown in Fig. 8, the individual electrodes 2, 2 adjacent each other in the thickness direction are electrically connected  
15 to each other by a conductive substance 14 in the through hole 13 by way of the intermediate electrode 16 between their connection portions 12, 12. When the through holes 13, 13 adjacent each other in the thickness direction are formed such that their center axes are  
20 displaced from each other, they can more reliably connect with the connection portion 12 or intermediate electrode 16 positioned therebetween.

[0028]

25 With respect to the external electrode 18 in the uppermost layer, four common electrodes 4 and the common electrode 19 in the lowermost layer align with

the intermediate electrode 6 interposed therebetween, whereas thus aligned electrodes 4, 6, 18, 19 are electrically connected to each other by the conductive member in the through hole 8.

5 [0029]

Such electric connections in the multilayer piezoelectric element 1 allow a voltage applied between a predetermined external electrode 17 and the external electrode 18 to cause a voltage between the individual electrode 2 and common electrodes 4, 19 aligned under the predetermined external electrode 17. As a consequence, an electric field occurs in the part held between the electrode portion 11 of the individual electrode 2 and the common electrodes 4, 19 as shown in Fig. 8, whereby this part is displaced as an active portion 21. Hence, by selecting an external electrode 17 for applying a voltage, the active portion 21 located under thus selected external electrode 17 among the active portions 21 corresponding to the respective individual electrodes 2 arranged in a matrix can be displaced in the thickness direction. Therefore, the multilayer piezoelectric element 1 can be employed as a driving source for various apparatus necessitating minute displacements such as valve control of micropumps.

10  
15  
20  
25

[0030]

When a voltage is applied between a predetermined individual electrode 2 and the common electrodes 4, 19 in thus configured multilayer piezoelectric element 1, the active portion 21 therebetween is displaced, whereby the electrode portion 11 of the individual electrode 2 bulges upward from the longitudinal direction like a bow. Here, the displacement in the thickness direction is restricted since the connection portion 12 of the individual electrode 2 is connected to the intermediate electrodes 16 positioned on the upper and lower sides by way of the conductive substance 14.

[0031]

However, as shown in Fig.3, the connection portion 12 is formed at a position shifted from the longitudinal centerline L of the electrode portion 11 at the end part 11a of the electrode portion 11 (i.e., displaced from a centerline orthogonal to the longitudinal direction of the electrode portion 11 as well). Also, the connection portion 12 is connected to the electrode portion 11 by way of the narrow neck portion 12a.

[0032]

As a consequence, the electrode portion 11 is more likely to flex in conformity to the displacement of the active portion 21 as compared with the case

where the connection portion 12 is directly formed on the centerline L extending along the longitudinal direction of the electrode portion 11, for example. Therefore, the multilayer piezoelectric element 1 can prevent the amount of displacement of the active portion 21 from decreasing, whereby the active portion can fully be displaced.

[0033]

Since the active portion 21 can fully exhibit its displacement, each individual electrode 2 can be made smaller, whereby the multilayer piezoelectric element 1 itself can be made smaller or the individual electrodes 2 can achieve such a high integration of 4 columns by 75 rows within a rectangle of 10 mm × 30 mm.

[0034]

After each external electrode 17 formed on the upper face of the uppermost piezoelectric layer 7 is provided with a silver baked electrode, a lead is connected thereto with soldering or the like while using a flexible printed circuit (FPC) board or the like. Since each external electrode 17 is positioned above the connection portion 12 of the individual electrode 2, the lead is prevented from pressing the electrode portion 11 and active portion 21 of the individual electrode 2 and inhibiting their

displacement.

[0035]

As mentioned above, the connection portion 12 is formed at a position shifted from the electrode portion 11 and thus is less susceptible to the displacement of the electrode portion 11, whereby the external electrode 17 positioned above the connection portion 12 is less vulnerable to the displacement. This can more reliably keep the connection between the connection portion 12 and the lead.

[0036]

In the following procedure, the multilayer piezoelectric element 1 is produced. First, a piezoelectric material mainly composed of ceramics such as lead zirconate titanate is mixed with an organic binder, an organic solvent, and the like, so as to yield a paste, from which green sheets to become the piezoelectric layers 3, 5, 7, 9 are formed. Also, a metal material composed of silver and palladium at a predetermined ratio is mixed with an organic binder, an organic solvent, and the like, so as to yield a conductive paste for forming an electrode pattern.

[0037]

Subsequently, the green sheets to become the piezoelectric layers 3, 5, 7, 9 are irradiated with laser light at predetermined positions, so as to form

through holes 8, 13. Thereafter, the through holes 8, 13 are subjected to filling screen printing with the conductive paste, so as to form a conductive substance 14. Further, the green sheets are subjected to screen printing with the conductive paste, so as to form electrodes 2, 4, 17, 19 and the like.

[0038]

The green sheets thus formed with the electrode patterns are laminated in the above-mentioned order and pressed in the laminating direction, so as to yield a green laminate. The green laminate is degreased, fired, and then polarized, so as to finish the multilayer piezoelectric element 1.

[0039]

In the making of the multilayer piezoelectric element 1 in the foregoing, electrodes for producing an electric field in the piezoelectric layer in cooperation with the electrode portions 11 of the individual electrodes 2 are formed as common electrodes 4, 19, whereby it becomes easier to form patterns of the electrodes and position them with respect to their opposing electrode portions 11.

[0040]

[Second Embodiment]

As shown in Fig. 9, the multilayer piezoelectric element 1 in accordance with the second embodiment

is constituted by a laminate pattern similar to that of the multilayer piezoelectric element 1 in accordance with the first embodiment but differs therefrom mainly in the form of individual electrodes 2. In the following, the multilayer piezoelectric element 1 in accordance with the second embodiment will be explained mainly in terms of differences from the multilayer piezoelectric element 1 in accordance with the first embodiment.

[0041]

As shown in Fig. 10, a number of individual electrodes 2 arranged in a matrix of 4 columns by 75 rows (only 4 columns by 18 rows being depicted for the sake of clarification), for example, and an intermediate electrode 6 connected to a conductive substance in a through hole 8 are formed on the upper face of each of the third, fifth, and seventh layers from the uppermost piezoelectric layer 7.

[0042]

As shown in Fig. 11, each individual electrode 2 includes a rectangular electrode portion 11 for producing, in cooperation with a common electrode 4, an electric field in the piezoelectric layer 3a. A square connection portion 12 connected to a conductive substance in the through hole 13 is integrally formed with one longitudinal end part 11a of the electrode

portion 11. While having the center of gravity position shifted from the longitudinal centerline L of the electrode portion 11, the connection portion 12 is positioned in a space S between the electrode portions 11, 11 adjacent each other in a direction  
5 orthogonal to the longitudinal direction.

[0043]

Individual electrodes 2 are also disposed in a matrix on the upper face of the ninth piezoelectric layer 3b as shown in Fig. 12. However, the ninth  
10 piezoelectric layer 3b differs from the piezoelectric layers 3a in that no through holes 13 are formed.

[0044]

As shown in Fig. 13, intermediate electrodes 16  
15 are formed on the upper face of each of the second, fourth, sixth, and eighth piezoelectric layers 5 from the uppermost piezoelectric layer 7 so as to oppose their corresponding connection portions 12 of the piezoelectric layer 3 in the thickness direction, and  
20 are connected to their corresponding conductive substances in the through holes 13.

[0045]

A common electrode 4 is formed on the upper face of the piezoelectric layer 5 so as to surround each  
25 of groups of the intermediate electrodes 16 in the first and second columns and groups of the intermediate

electrodes 16 in the third and fourth columns with a predetermined gap therebetween, whereas the common electrode 4 is connected to a conductive substance in the through hole 8. As shown in Fig. 11, the common electrode 4 also has a shape to overlay the electrode portions 11 of the piezoelectric layer 3 across the piezoelectric layers 3, 5.

[0046]

As shown in Fig. 14, the upper face of the uppermost piezoelectric layer 7 is formed with external electrodes 17 opposed to their corresponding intermediate electrodes 16 of the piezoelectric layer 5 in the thickness direction, whereas the external electrodes 17 are connected to their corresponding conductive substances in the through holes 13. Further, an external electrode 18 is formed so as to oppose to the intermediate electrode 6 of the piezoelectric layer 3 in the thickness direction, and is connected to the conductive substance in the through hole 8. As in Fig. 7, the upper face of the lowermost piezoelectric layer 9 is formed with a rectangular common electrode 19 having an outer form equivalent to that of the common electrode 4 of the piezoelectric layer 5.

[0047]

Laminating the piezoelectric layers 3, 5, 7, 9

formed with the electrode patterns as in the foregoing achieves electric connections similar to those in the multilayer piezoelectric element 1 in accordance with the first embodiment. In the piezoelectric layer 3 of the multilayer piezoelectric element 1 in accordance with the second embodiment, however, the connection portion 12 of each individual electrode 2 is positioned in the space S between the electrode portions 11, 11 adjacent each other. As a consequence, the individual electrodes 2 can be disposed more efficiently on the piezoelectric layer 3. This makes it possible to reduce the size of the multilayer piezoelectric element 1 or achieve higher integration of the individual electrodes 2, while keeping the area of each active portion in the multilayer piezoelectric element 1.

[0048]

From a different viewpoint, assuming that the multilayer piezoelectric element 1 has a fixed size, each electrode portion 11 can be made longer in the longitudinal direction thereof since the connection portion 12 is positioned in the space S between the electrode portions 11, 11, whereby the active length of each active portion 21 in the multilayer piezoelectric element 1 can be made longer.

[0049]

The present invention is not restricted to the above-mentioned first and second embodiments. For example, though the first and second embodiments relate to cases where the electrode portion 11 of each individual electrode 2 has a rectangular form whereas each connection portion 12 has a square form, the electrode portion 11 and connection portion 12 may have various forms. For example, the electrode portion 11 and connection portion 12 may have elliptical and circular forms, respectively. Even in such various forms, operations and effects similar to those in the first and second embodiments are obtained when each individual electrode 2 is formed such that the connection portion 12 is shifted from the longitudinal centerline L of the electrode portion 11.

[0050]

[Effects of the Invention]

As explained in the foregoing, the multilayer piezoelectric element in accordance with the present invention can prevent the amount of displacement of active portions in piezoelectric layers from decreasing.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is an exploded perspective view of a first

embodiment of the multilayer piezoelectric element in accordance with the present invention.

[Fig. 2]

Fig. 2 is a plan view of the third, fifth, and seventh piezoelectric layers in the multilayer piezoelectric element shown in Fig. 1.

[Fig. 3]

Fig. 3 is an enlarged plan view showing a main part of the piezoelectric layers shown in Fig. 2.

[Fig. 4]

Fig. 4 is a plan view of the ninth piezoelectric layer in the multilayer piezoelectric element shown in Fig. 1.

[Fig. 5]

Fig. 5 is a plan view of the second, fourth, sixth, and eighth piezoelectric layers in the multilayer piezoelectric element shown in Fig. 1.

[Fig. 6]

Fig. 6 is a plan view of the uppermost piezoelectric layer in the multilayer piezoelectric element shown in Fig. 1.

[Fig. 7]

Fig. 7 is a plan view of the lowermost piezoelectric layer in the multilayer piezoelectric element shown in Fig. 1.

[Fig. 8]

Fig. 8 is an enlarged sectional view taken in a direction perpendicular to the longitudinal direction of the multilayer piezoelectric element shown in Fig. 1.

5 [Fig. 9]

Fig. 9 is an exploded perspective view of a second embodiment of the multilayer piezoelectric element in accordance with the present invention.

[Fig. 10]

10 Fig. 10 is a plan view of the third, fifth, and seventh piezoelectric layers in the multilayer piezoelectric element shown in Fig. 9.

[Fig. 11]

15 Fig. 11 is an enlarged plan view showing a main part of the piezoelectric layers shown in Fig. 10.

[Fig. 12]

Fig. 12 is a plan view of the ninth piezoelectric layer in the multilayer piezoelectric element shown in Fig. 9.

20 [Fig. 13]

Fig. 13 is a plan view of the second, fourth, sixth, and eighth piezoelectric layers in the multilayer piezoelectric element shown in Fig. 9.

[Fig. 14]

25 Fig. 14 is a plan view of the uppermost piezoelectric layer in the multilayer piezoelectric

element shown in Fig. 9.

[Explanation of Reference Numerals]

1...multilayer piezoelectric element,  
2...individual electrode (first internal electrode),  
5 3, 5...piezoelectric layer, 7...piezoelectric layer  
(outermost layer), 4, 19...common electrode (second  
internal electrode), 8, 13...through hole, 11...electrode  
portion, 12...connection portion, 14...conductive  
substance, 17, 18...external electrode, L...centerline,  
10 S...space.

[Document Name] ABSTRACT

[Abstract]

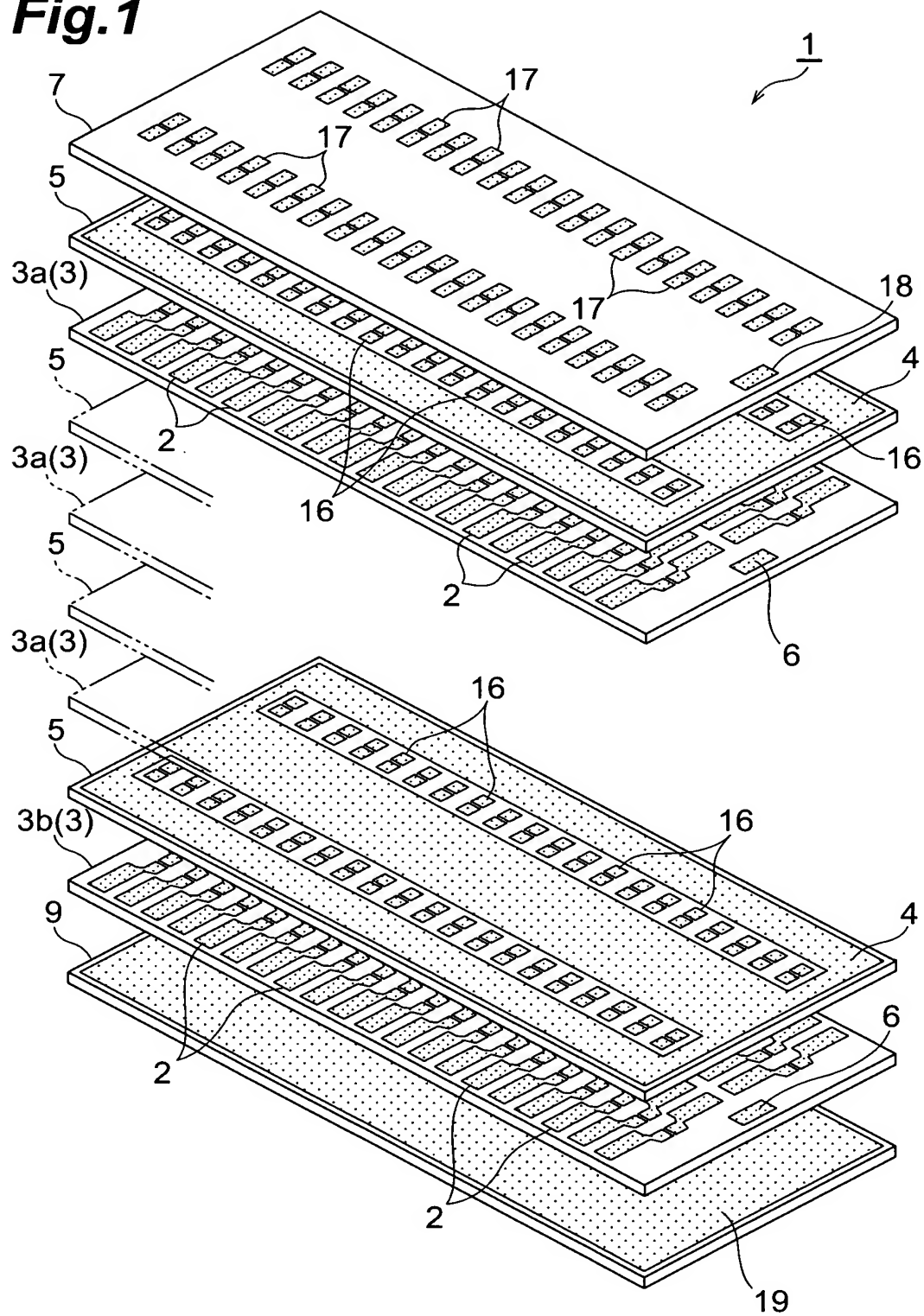
[Problem] It is an object of the present invention to provide a multilayer piezoelectric element which can prevent the amount of displacement of active portions in piezoelectric layers from decreasing.

[Means of Solution] In a piezoelectric layer 3 of a multilayer piezoelectric element, a portion held between an electrode portion 11 of an individual electrode 2 and a common electrode 4 becomes an active portion. When a voltage is applied between the individual electrode 2 and common electrode 4, the active portion is displaced. The individual electrode 2 includes a connection portion 12 connected to the conductive substance within a through hole 13 of the piezoelectric layer 3. The connection portion 12 is formed at a position shifted from the longitudinal centerline L of the electrode portion 11. This can restrain the displacement of the electrode portion 11 following the active portion of the piezoelectric layer 3 from being suppressed by the connection with the conductive substance as compared with a case where the connection portion 12 is formed on the centerline L of the electrode portion 11. Therefore, the amount of displacement of the active portion in the piezoelectric layer 3 can be prevented from

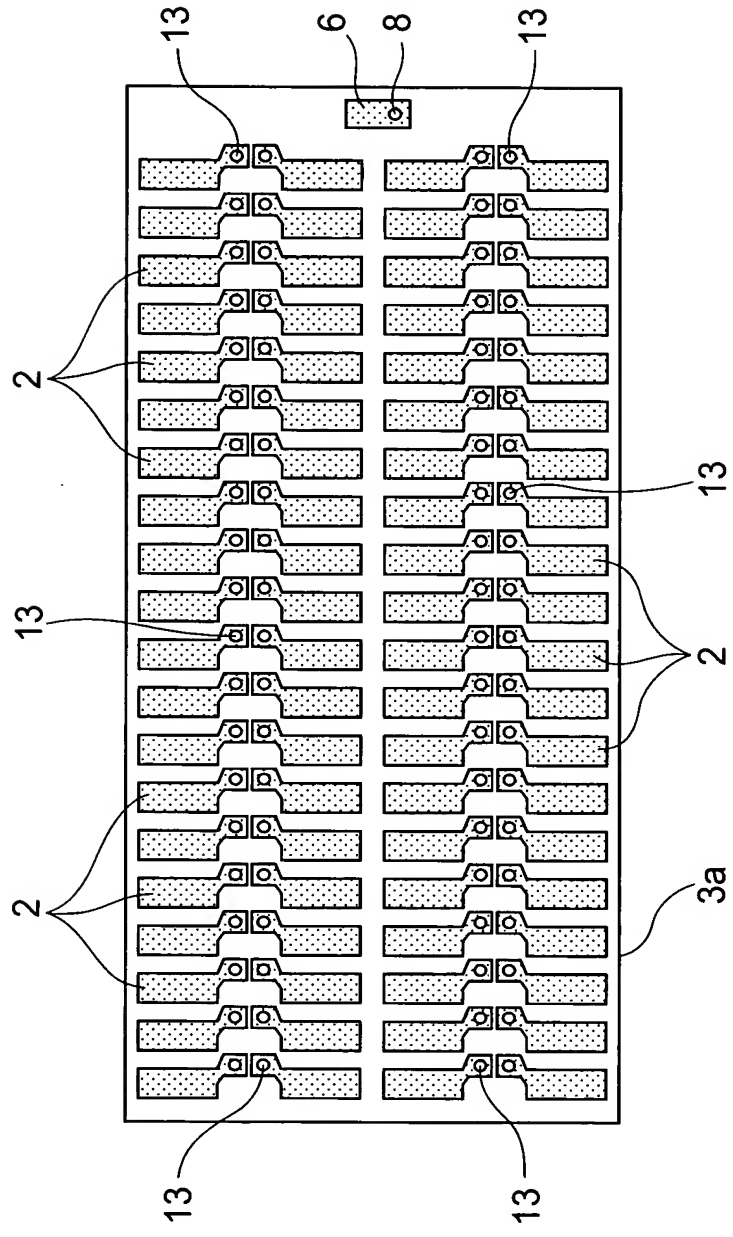
decreasing.

[Selected Drawing] Fig. 3

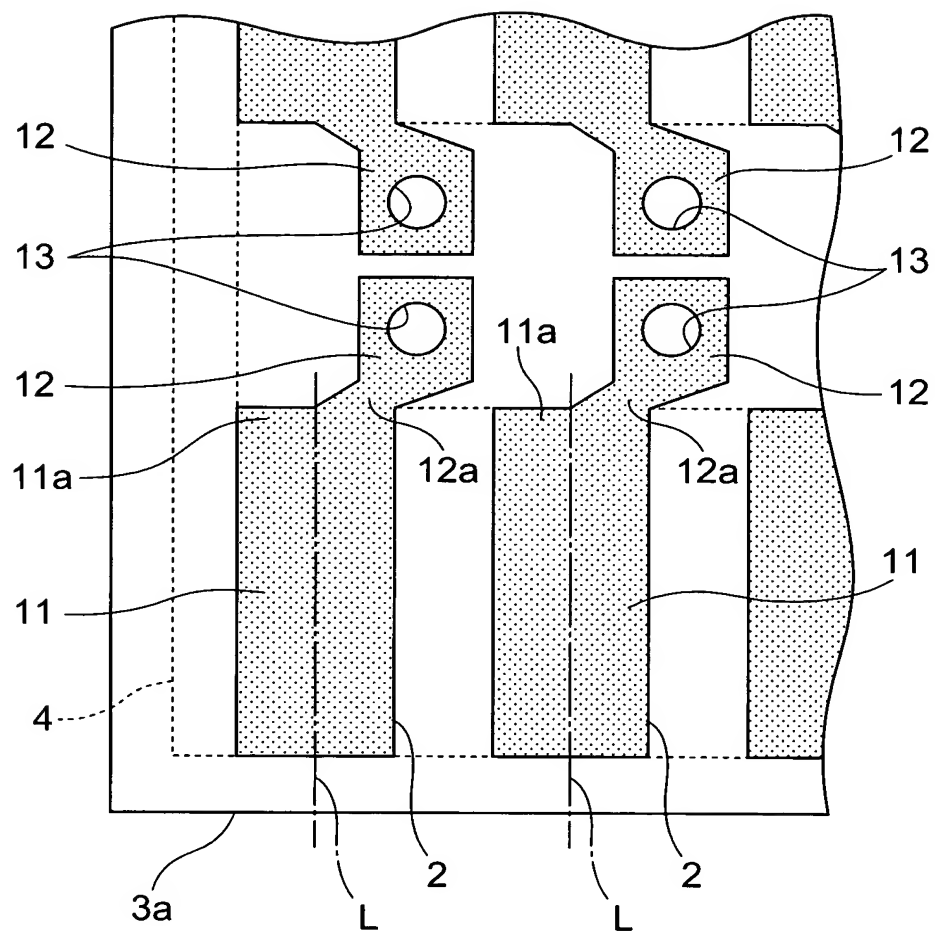
**Fig.1**



**Fig.2**



**Fig.3**



**Fig.4**

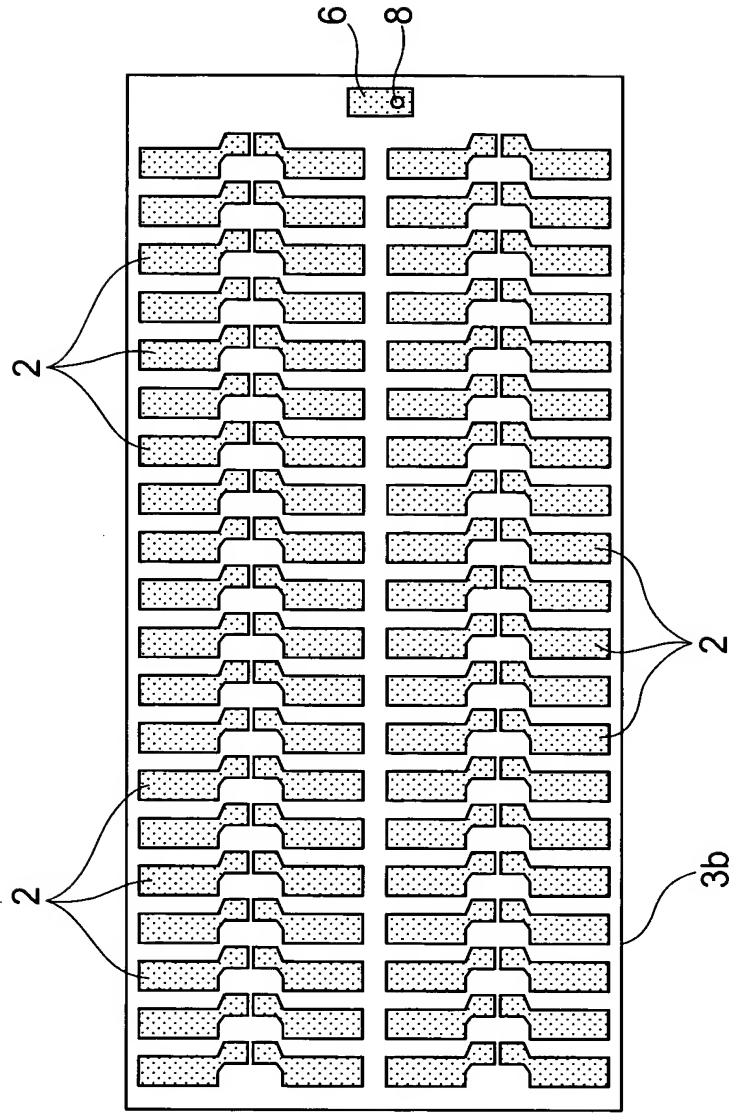


Fig.5

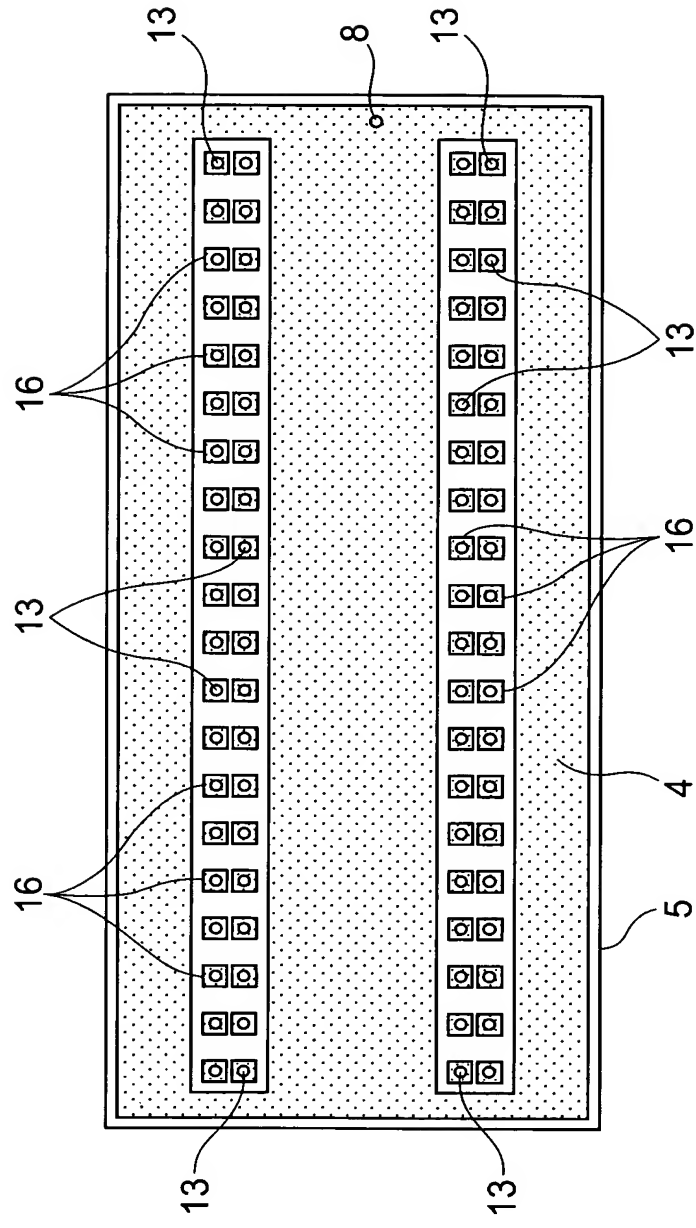
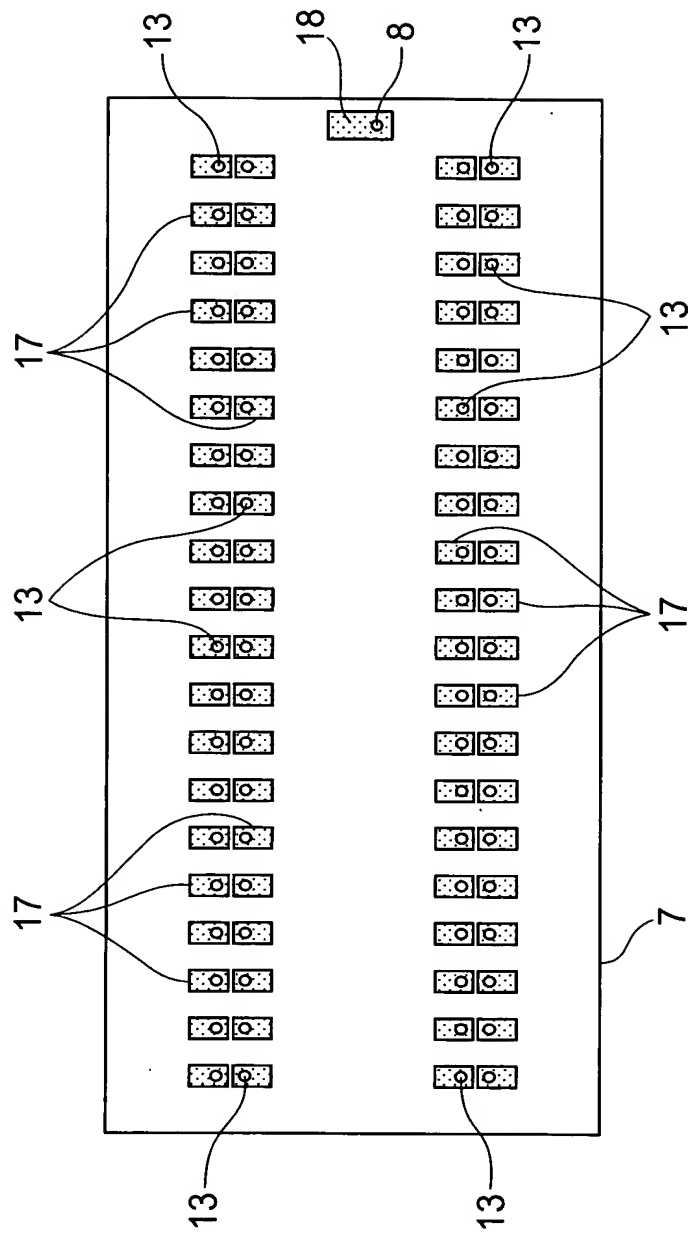
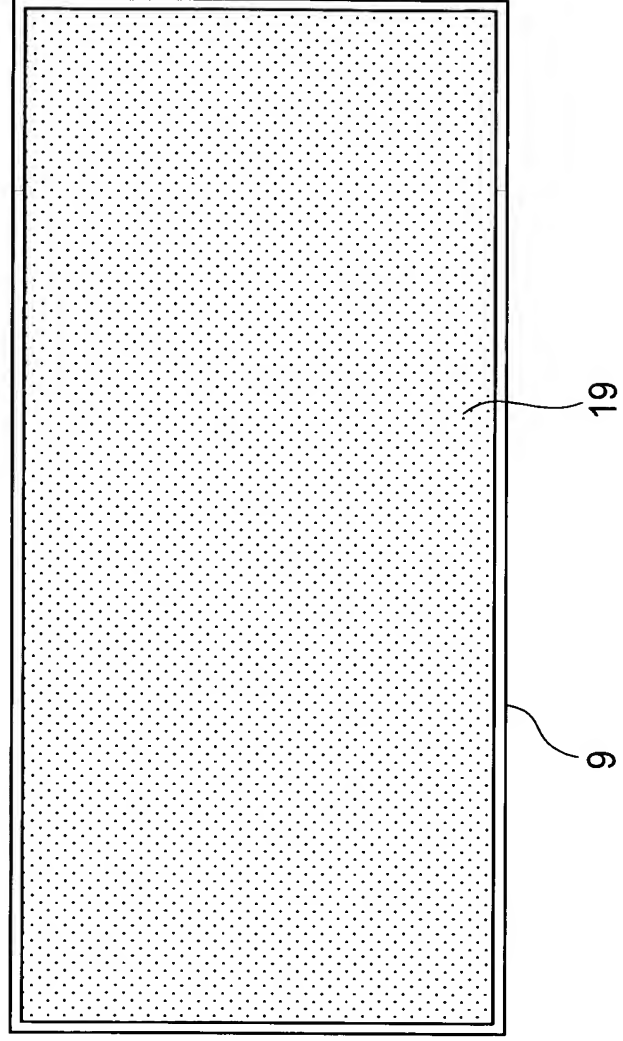


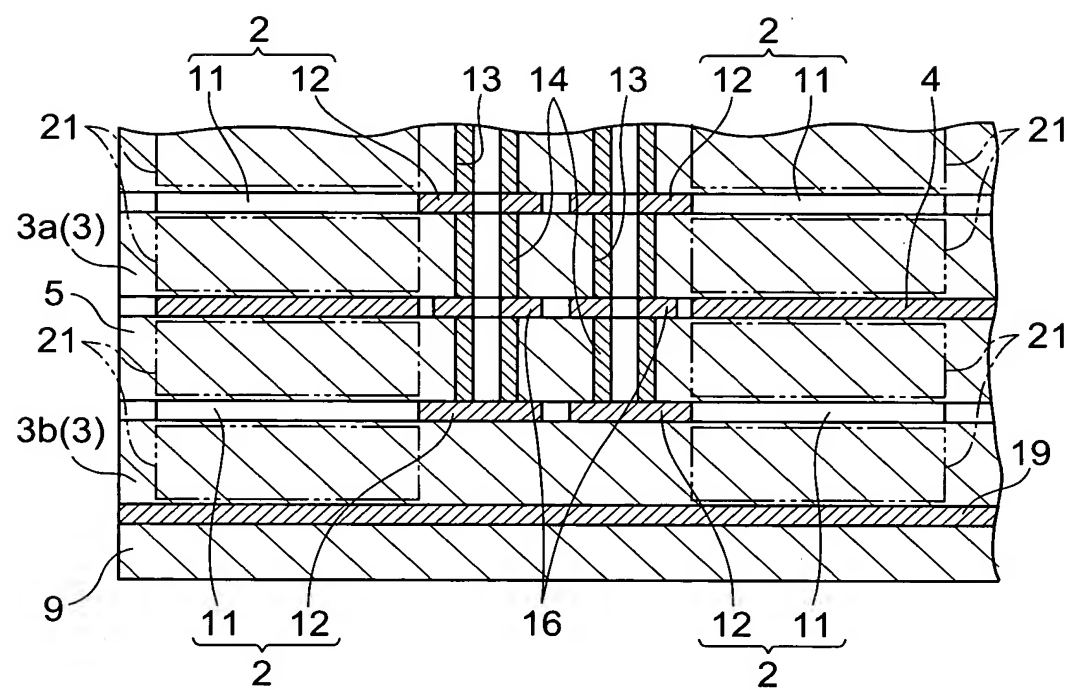
Fig.6



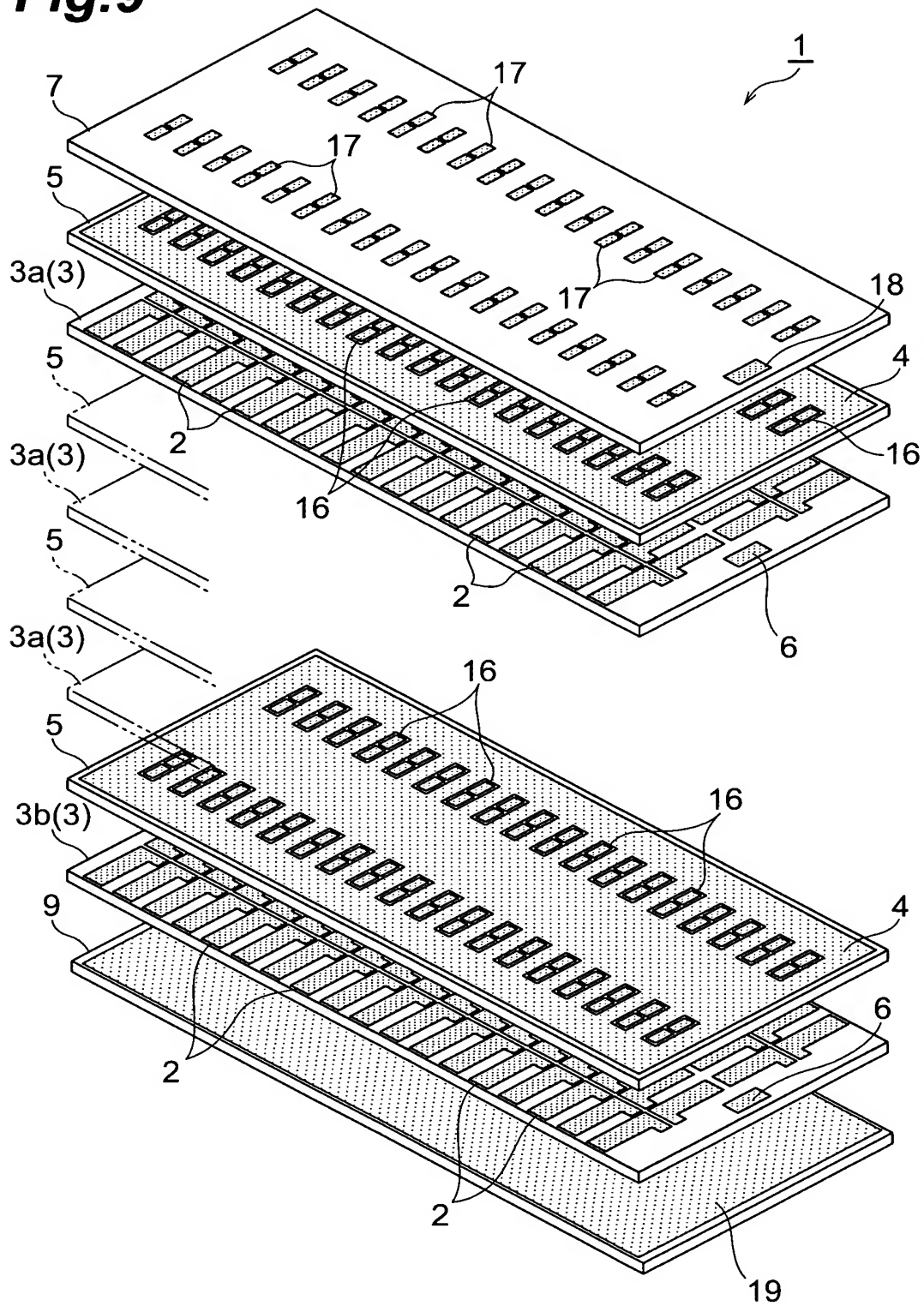
**Fig.7**



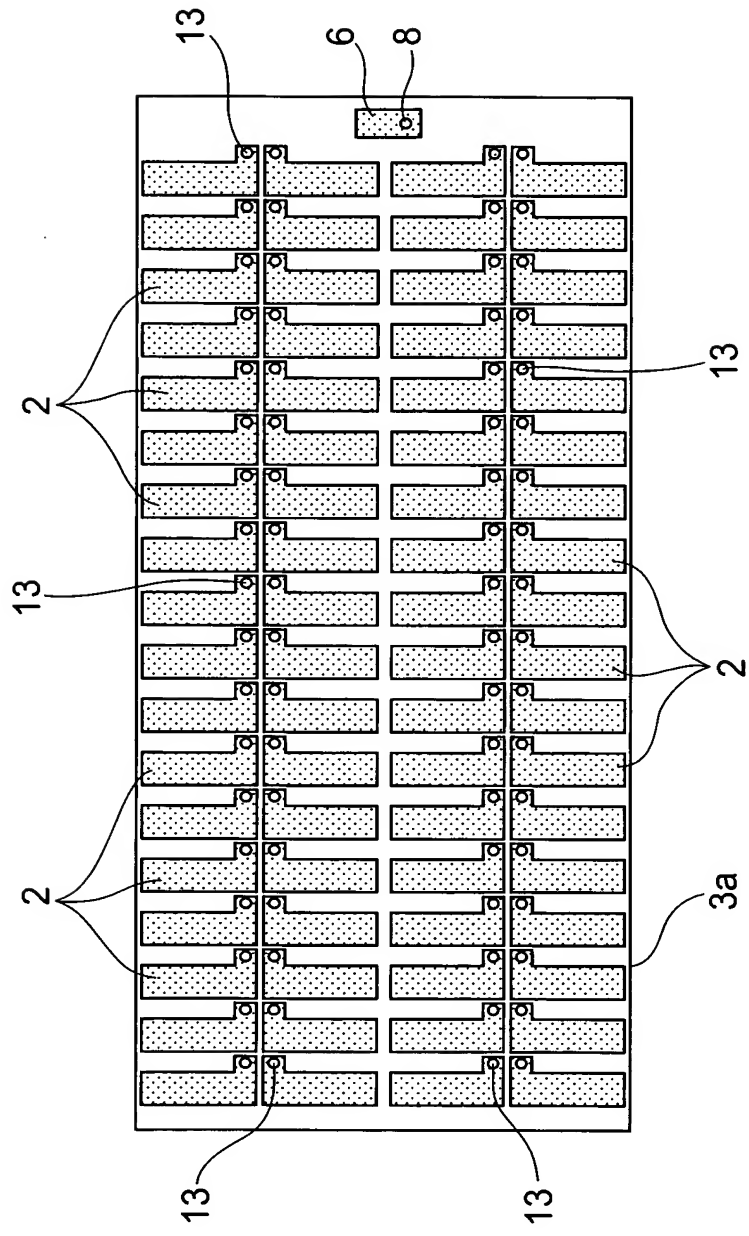
**Fig.8**



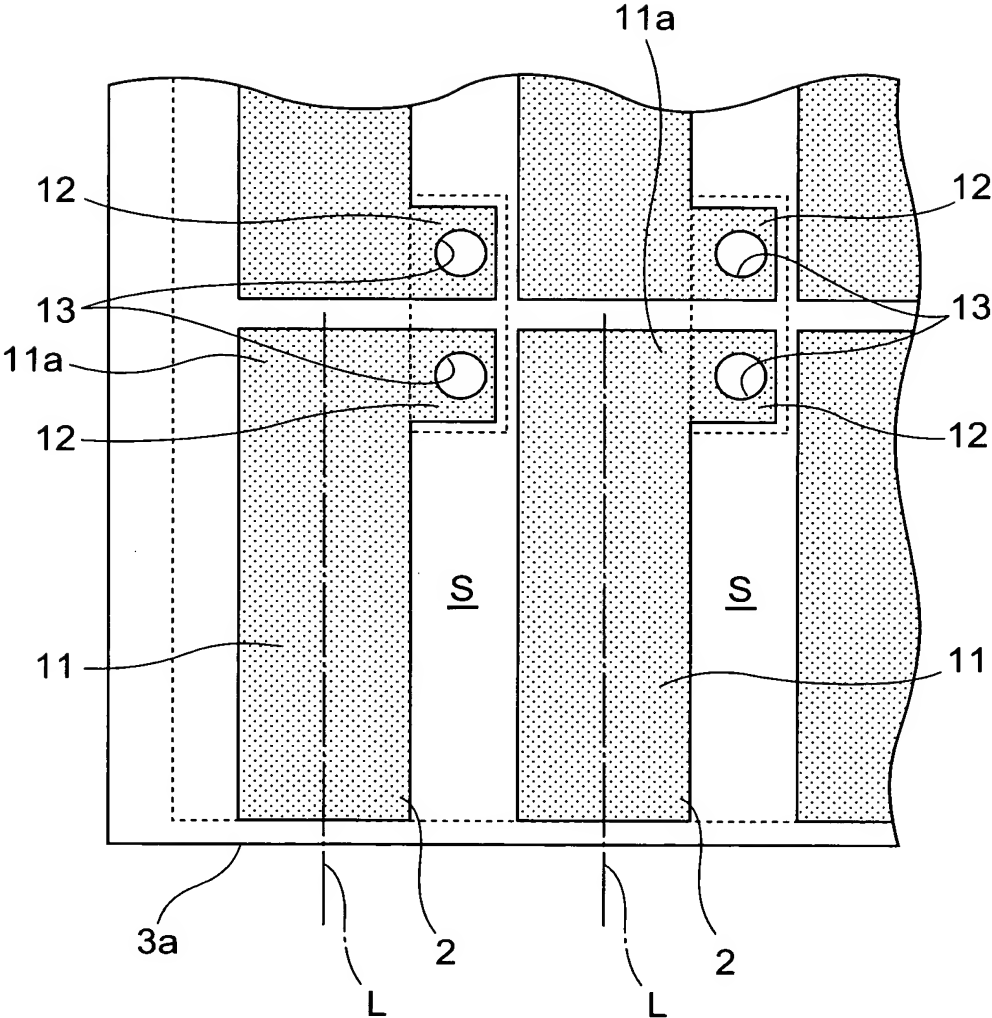
**Fig.9**



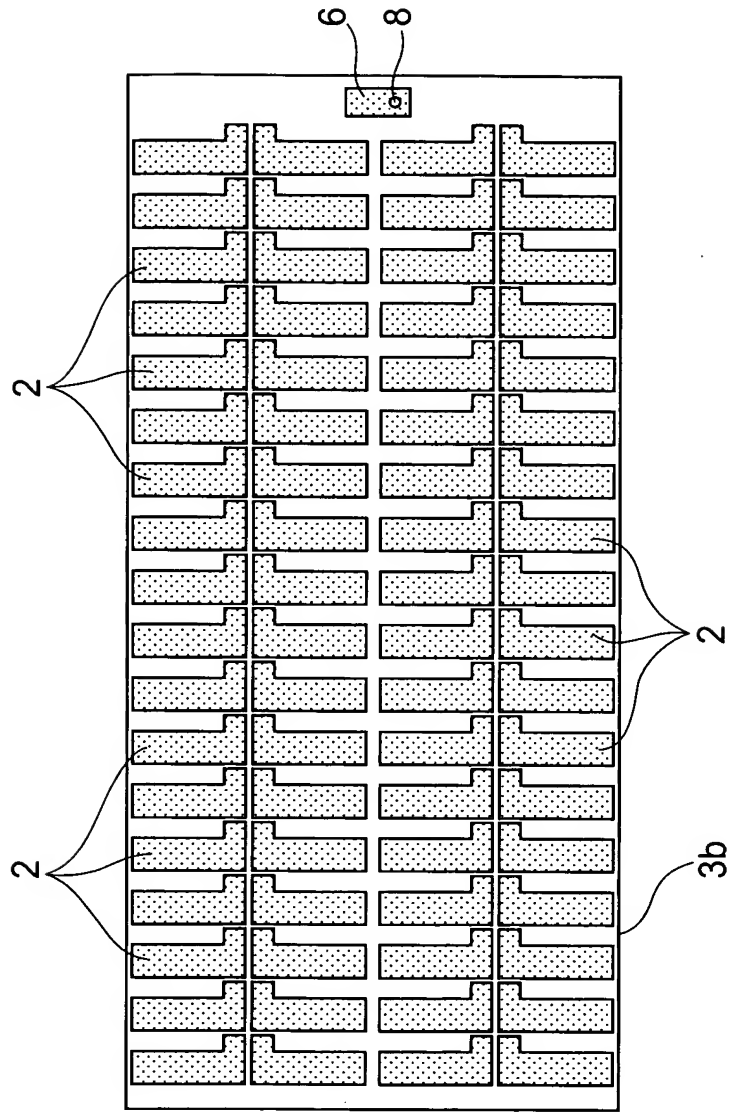
**Fig.10**



**Fig.11**



**Fig.12**



**Fig.13**

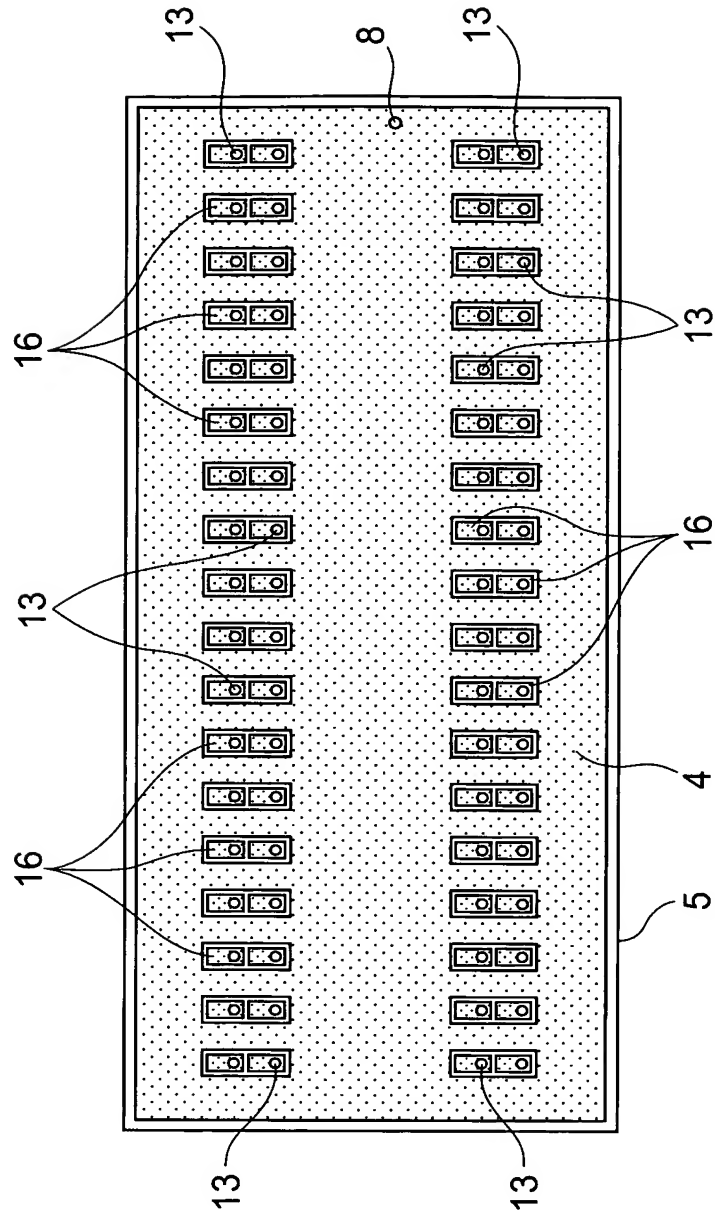


Fig.14

